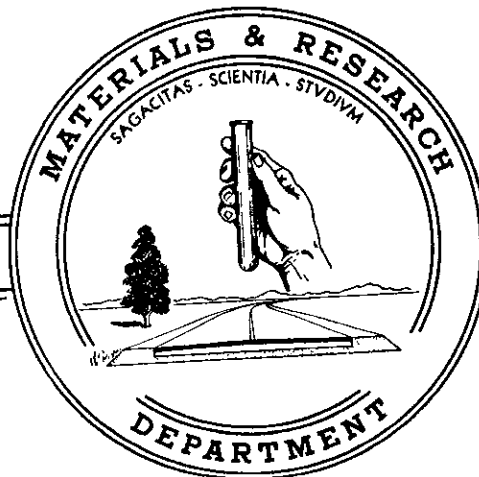


STATE OF CALIFORNIA
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS



A REPORT ON
AN INVESTIGATION OF THE CORROSION OF
REINFORCING STEEL IN THE OTEN WASH BRIDGE
NO. 58-277 ON ROAD XI-Imp-187-G

September, 1959



59-02

State of California
Department of Public Works
Division of Highways
Materials and Research Department

September 15, 1959

Lab. Auth. 100-S-6181

Mr. F. W. Panhorst
Assistant State Highway Engineer
Division of Highways
Sacramento, California

Attention: Mr. R. J. Ivy


Dear Sir:

Submitted for your consideration is:

A REPORT ON
AN INVESTIGATION OF THE CORROSION OF
REINFORCING STEEL IN THE OTEN WASH BRIDGE
NO. 58-277 ON ROAD XI-Imp-187-G

Study made by Structural Materials Section
Under general direction of J. L. Beaton
Work supervised and reported by R. F. Stratfull

Very truly yours,


F. N. Hveem
Materials and Research Engineer

RFS:rl
cc: JWTrask
BTremper
District XI (2)
Bridge Dept. (10)

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I. INTRODUCTION

On February 5, 1959, Mr. F. W. Panhorst requested by letter that the Materials and Research Department perform a corrosion study to determine the cause of corrosion of the reinforcing steel in the Oten Wash Bridge, and the most feasible method of repair.

Historically the bridge was constructed during 1950 under contract number 1-11VC52.

On January 16, 1959, the Bridge Department made an investigation of the reinforced concrete bearing piles. Extensive cracking in the piles was observed apparently caused by expansion of the reinforcing bars due to corrosion.

Samples of concrete from the structure were sent to the Laboratory to determine whether there were salts or other contaminants in the concrete that could be a cause of the corrosion.

The results of the chemical analysis of the concrete fragments were reported by letter dated February 20, 1959, indicated that the chloride concentration ranged between 0.16% and 0.57%, while the sulfate content was between 0.09% and 0.29%. Chemical concentrations similar to these values have been found in other structures that have given evidence of severe corrosion.

Also in the same letter dated February 20, 1959, Mr. Bailey Tremper suggested that the mechanism of corrosion in this case may be similar to that occurring on the San Mateo-Hayward Bridge. Because of the suggested possibility of macro-galvanic corrosion, a field survey was made to determine the cause, if possible.

II. SUMMARY AND CONCLUSIONS

The reinforcing steel in the Oten Wash Bridge is corroding as a result of both macro and micro galvanic corrosion. Potential measurements on the surface of the concrete indicate the presence of large scale macro corrosion cells. However, measurements in some locations indicate that to a lesser degree the deterioration may also be the result of micro corrosion cells. The micro galvanic corrosion cell in general represents a condition where the anode and cathode are closely related as exemplified by atmospheric corrosion; whereas in the case of the macro galvanic cell, the anode is usually separated from the cathode by some distance, which may be as much as several feet.

As the Oten Wash Bridge is located in the Colorado desert, the corrosion of this structure appears unusual considering the arid environment. Therefore, an inspection of 66 bridges on Route 187, between Niland and Mecca, was undertaken to determine if there were other structures in the same general environment that were suffering from corrosion.

The results of this survey indicated that 20 out of 66, or 30% of the structures have various degrees of corrosion of the reinforcing steel. Also, the survey indicated that in this geographic area, alkali salts coupled with sub-surface moisture may be the contaminants which are causing the corrosion of the steel.

There were four structures on which "pop-outs" of concrete were observed. Such pop-outs of concrete are sometimes associated with alkali-aggregate reaction. The records were consulted to determine whether the materials that were used in construction were reactive. It was found that the aggregate, which was washed before use, is considered to be non-reactive. However, the cement that was used was a Type II of 0.66 percent alkali, which is 0.06% greater than our existing specification limit of 0.60%. It was not determined whether the pop-out of the concrete was the result of reactive aggregate, high alkali cement, or due to some other cause such as the inclusion of shale or other expansive particles in the aggregates.

It is recommended that the repair of this structure be accomplished by removing the deteriorated concrete, cleaning and repairing the steel (where needed), and guniting the exposed areas.

III. RECOMMENDATIONS

It is recommended that:

1. The specifications for and the type of repair to the Oten Wash Bridge be the same as that used for the San Mateo-Hayward Bridge IV-Ala, SM-105-B, A, Contract No. 57-SMAC6 (The generalization of the specifications are in the Appendix).
2. The repairs to all piles extend from the edge of the cap to a minimum distance of 2-feet below the flow line of the channel, or to a point 18-inches beyond the observed locations of corrosion, whichever is the greater overall distance.
3. Both edges of the deck be repaired in their entirety.
4. This investigation be continued to investigate other concrete structures to determine the extent of corrosion and the possibility that alkali soils may be the cause of corrosion elsewhere.
5. This investigation be continued to determine whether alkali soils can be a cause of an alkali-aggregate type of reaction in concrete.
6. This investigation be continued to determine if the effect of such corrosive soils or waters can be predicted.

IV. TESTS

A. The electrical potential of reinforcing steel

A complete potential survey was made of the reinforcing steel in a manner similar to that performed on other structures. The underside of the deck was laid out in two foot squares and potentials of the steel were measured to determine whether there were macro-galvanic corrosion currents. Exhibits I, II, and III, included in the Appendix, show the equipotential contours obtained from the measurements.

The results of the potential measurements indicate that there are macro-galvanic corrosion cells affecting the rusting of the steel. However, some of the measurements also indicate that macro-galvanic cell action may not be the only cause of corrosion and that micro-galvanic cells may also exist. This fact is indicated by the high electrical resistivities and small potential gradients that were measured in some locations. In some of the measurements the resistivity of the concrete approximates that of sun baked granite rock.

That the corrosion of this structure may be a combination of macro and micro galvanic corrosion cells is not considered to be unusual as there is no known evidence to indicate that corrosion must be limited to a single cause or mechanism.

B. The electrical resistivity of the concrete

The electrical resistivity of the concrete was measured on the piles, caps and the underside of the deck. The measurements were made with the same instruments that were utilized on the San Mateo-Hayward Bridge.

The results of the resistivity measurements indicated that the concrete measured from 3385 to 600,000,000 ohm cm. Generally, the resistivity of the concrete is greater than 1,000,000 ohm cm. There was one location on the retaining wall where the measured resistance was 3,385 ohm cm and one location on the deck found to be 9,925 ohm cm.

The resistivity measurements on the San Mateo-Hayward Bridge indicated that cracking of the concrete did not occur when the resistivity was in excess of 60,000 ohm cm.

There is the possibility that the resistivity measurements on this structure are not indicative of the true conductivity of the concrete, as there was a wind storm that lasted for three days just prior to the time the measurements were made. The wind storm may have caused excessive drying of the concrete, which could have resulted in measurements that are not representative of "normal" conditions.

Generally, it would be expected that concrete in the desert air would be so dry that it could almost be considered a dielectric. However, there were measurements on the deck that were indicative of high moisture content. These seem to point out that the concrete may absorb moisture from the damp soil in the channel. If the concrete can absorb moisture from the channel, it is also probable that the salts or alkalies which are contained in that moisture can be transported through the concrete to the surface of the reinforcing steel and cause it to corrode.

By the same token, it may be that other structures placed in the same type of environment at other locations in the State would eventually be subject to corrosion of the reinforcing steel.

C. Environmental tests

When observing the presence of corrosion on this and other structures in the area, it appeared that corrosion of the reinforcing steel was more prevalent in those structures in which the channel soils were observed to contain alkali.

A confirmation of the observation of alkali and the presence of corrosion is indicated by the following tabulations:

TABLE I

The Environment and the Presence of Reinforcing
Steel Corrosion

Corrosion	Flow		Observed presence of alkali in channel		
	None	Damp or yes	None	Trace	Greater than Trace
YES	*11	*9	*2	*3	*15
	55%	45%	10%	15%	75%
NO	*34	*12	*24	*13	*9
	74%	26%	52%	28%	20%

* Number of observations.

As will be noted in Table I, the greater the observed concentration of alkali in the channel the greater the percentage of structures in which reinforcing steel was observed to be corroding. Conversely, when the channel was observed to be dry and the presence of alkali was not observed, the evidence of corrosion decreased.

Therefore, these data confirm the well known fact that alkali soils may adversely affect the durability of reinforced concrete structures.

Inasmuch as there is flow in the channels only once or twice a year, it does not appear that the rapid contamination of the concrete could have been accomplished by "splash action". Also, the potential contours and the inspection did not indicate any particular pattern or area of the structures that was corroding which could be definitely linked to air-borne salt from the Salton Sea. It appears that the contamination of the concrete by salts or alkali, which are present in the soil, must be carried into the structure by capillary, or other type of internal action.

The subject of alkalies in soils and their effect on corrosion has not been fully explored in the literature. There are references which indicate that in certain areas the alkali salts are not corrosive, while in other areas they cause severe corrosion. Normally, when discussing alkalies, it is the sodium and potassium salts which are considered to be detrimental to metal.

Fourteen soil samples were obtained from the channels of some of the structures inspected. The soil samples encompassed locations where structures were both corroded and non-corroded and are listed in Table II, Page 7.

As will be noted on Exhibit IV and Table II, there appears to be a definite relationship between the minimum soil resistivity and the concentrations of Chlorides, sodium, sulfates and dissolved solids. Because of the few samples, it cannot be assumed that this apparent correlation is necessarily true for soils in other areas of the State.

Also included on Exhibit IV, is the observation of alkali deposits on the channel plotted at the measured minimum soil resistivity. From this exhibit, it could be inferred that when a trace of either white or black alkali is observed on the soil, that the minimum soil resistivity will be in the neighborhood of 200 ohm cm. As a point of reference for these values, the resistivity of sea water is in the range of 50 to 100 ohm cm.

It is interesting to note that some of the minimum resistivities of alkali soils were measured to be 10 ohm cm.

In this geographic area, alkali soils were found which have a minimum of approximately 100 ppm chlorides, 1000 ppm of sodium, 1000 ppm of sulfates and about 5000 ppm of dissolved solids. The potassium salts ranged between 8 to 1000 ppm and were not plotted as the data were too scattered to define a linear relationship between resistivity and potassium. However, as a rule of thumb, when the soil resistivity was less than 200 ohm cm the potassium varied from approximately 100 ppm to 1000ppm. When the soil resistivity was in excess of 200 ohm cm the potassium concentration ranged from about 100 ppm at 200 ohm cm to 8 ppm at 8500 ohm cm.

TABLE II
CHEMICAL ANALYSIS OF NATURAL SOILS

Alkali	Corrosion	Potassium	Sodium	Chlorides	Solids	Sulfates	Total Alkali as CaCO ₃		pH	Resistivity	Location
C	Yes	440	33000	8600	190,000	28,000	1400	8.0	10	Imp-187-F,	Sta 84+98
C	No	1000	53000	12440	472,000	172,000	9000	8.1	10	Riv-187-B,	Sta 195+
C	Yes	360	18000	5000	110,930	10,000	660	7.4	12	Imp-187-F,	Sta 3.82+04
C	Yes	400	20000	3700	74,840	6,100	600	8.4	15	Imp-187-G,	Sta 2+42
C	Yes	700	19000	3700	67,150	5,500	740	8.3	16	Imp-187-F,	Sta 601+55
C	No	500	29000	1600	119,630	45,000	31000	9.4	20	Riv-187-B,	Sta 219+25
T	Yes	100	900	80	3,400	620	1200	8.0	140	Imp-187-F,	Sta 11+51
T	Yes	110	1400	230	7,950	2,130	640	7.8	160	Imp-187-G,	Sta 57+20
N	No	65	750	30	3,260	720	1400	8.1	325	Imp-187-F,	Sta 235+86
-	-	40	300	30	2,700	500	900	8.3	650	Frink Pit	
N	No	30	80	10	800	140	480	8.5	1900	Riv-187-A,	Sta 263+65
N	No	25	50	10	930	140	500	8.5	3000	Riv-187-G,	Sta 116+30
N	No	18	50	10	1,050	120	580	8.3	3000	Riv-187-F,	Sta 100+05
-	-	8	30	10	1,650	Nil	240	8.6	8500	Mineral Spa Pit	

*NOTE: Alkali is that observed on surface of ground, C = considerable,

T = Trace, N = None. Chemical concentrations are in parts

per million.

Also included on Exhibit IV are notations indicating whether the reinforcing steel was rusted at the locations where the soil samples were obtained. Perhaps by chance, the indicated soil resistivity of 200 ohm cm again appears to be the limit where corrosion of reinforcing steel was observed. It would be no more than conjecture to state that 200 ohm cm may be the limit of anything, as there is no comparison based on time for any of these observations; and there is a possibility that corrosion may occur at a later date.

However, it is interesting to note the apparent relationship between soil resistivity and the presence of corrosion and also alkali. With additional study, it may be possible to design the corrosion resistance of a structure according to the environment, especially when there is some definite measure of the aggressiveness of the environment.

Also included is Table III, which shows the chemical analysis of concrete fragments earlier obtained by the Bridge Department.

This analysis of the concrete indicates the same range of values found in the San Mateo-Hayward Bridge.

TABLE III

Chemical Analysis of Concrete Fragments

	Chlorides Water-Soluble	Sulfates Water-Soluble	Sulfates Acid-Soluble
Pile #1, Bent #2, Soft Mortar	0.16%	0.09%	0.09%
Pile #1, Bent #2, Strong Mortar	0.57%	0.06%	0.20#
Super-structure W. Side Span 3	0.30%	0.14%	0.29%

V. DISCUSSION

This investigation has resulted in some interesting observations. For instance; there are indications that capillary, or other internal forces may be mainly responsible for carrying the contaminants into the concrete, which have resulted in the corrosion of steel in concrete. It may not be feasible to change concrete into an impermeable material without drastically affecting the

economics of its use. However, it may be possible to inhibit the loss of moisture and thus maintain the moisture in the concrete at a relatively constant level. The prevention of the loss of moisture and movement of water in concrete could restrict the buildup of contaminants due to evaporation.

In addition to the evidence of internal movement of moisture, this limited study has also indicated that corrosion of the reinforcing steel may occur at any location where moisture and salts are found.

Another interesting phenomenon that was observed was the concrete "pop-outs". That these "pop-outs" might be the result of alkali aggregate reaction is a matter of conjecture. The aggregate used in the construction of these bridges has been generally recognized as non-reactive. Also, the 0.06% excess of alkali, over the presently accepted limits in cement could be sufficiently abnormal to justify it as the single cause of the spalling. It should be clearly understood that the quantity of spalls observed was small and not a matter for concern for the structural safety of the bridges.

The phenomenon of concrete "pop-outs" has been brought out as an observation and may merit some future study.

As macro and micro galvanic corrosion of the reinforcing steel and concrete "pop-outs" have been observed, it appears prudent to continue this investigation to determine whether the observed phenomenon is peculiar to the bridges observed, or if the deterioration is occurring in other locations.

It also appears that if the indicated correlation on Exhibit IV, Chemical analysis of soils plotted against minimum soil resistivity can be verified, such a chart correlated to corrosion problems would be invaluable in the prediction of corrosive areas and future structures can be designed for resistance to deterioration.

It is recommended that this investigation be continued to encompass the other areas of the State to determine if there is additional evidence of concrete deterioration. Also, it is recommended that the investigation include an attempt to determine whether there are physical or chemical means by which corrosive areas can be predicted and, whether alkali deposits can cause deterioration of concrete similar to that found in alkali aggregate reactions.

VI. GENERALIZED SPECIFICATIONS

These general specifications are based upon those suggested by M. W. Gewertz in Part I, Method of Repair in a paper entitled "Causes and Repair of Deterioration to a California Bridge Due to the Corrosion of Reinforcing Steel in a Marine Environment", H.R.B. Bulletin #80, 1957. The specified method of shotcrete repair is based upon the A.C.I. standard of "Recommended Practices for the Application of Mortar by Pneumatic Pressure" (ACI 805-51)

"A minimum of 2 inches of concrete is to be removed behind reinforcement requiring sandblasting in order to facilitate thorough cleaning of the back side of reinforcement. Existing reinforcement is thoroughly sandblasted prior to installing additional bar, mesh, or expanded metal lath reinforcement. The prepared member is again lightly blasted shortly prior to placing shotcrete. This serves to clean all welds and to remove any light film of rust which may exist on the added reinforcement, or may have developed overnight on previously cleaned reinforcement.

Shotcrete is applied in not less than two courses due to the depth of material required to be placed. In general, the first course is applied to cover all reinforcement and the second course conforms to the dimensions desired (2nd course to be a minimum of 1 inch thickness)".

Appropriate detailed specifications are to be found in Contract No. 57-SMAC6, San Mateo-Hayward Bridge, IV-SM, Ala-105-B,A.

APPENDIX

- Exhibit I. Equi-Potential Contours of Underside of Deck,
 Oten Wash Bridge No. 58-277, Most Southerly Span
- II. Equi-Potential Contours of Underside of Deck,
 Oten Wash Bridge No. 58-277, Center Span
- III. Equi-Potential Contours of Underside of Deck,
 Oten Wash Bridge No. 58-277, Most Northerly Span
- IV. Chemical Analysis of Soils Plotted Against Minimum
 Soil Resistivity

CHEMICAL ANALYSIS OF SOILS PLOTTED AGAINST MINIMUM SOIL RESISTIVITY

